



# **Landsat 8 View Angle Generation**

**Jim Storey, Mike Choate  
USGS/SGT**

**October 30, 2013**

# View Angle / Sun Angle Generation

- ◆ **At the February Science Team meeting the CalVal Team was requested to develop a method to either:**
  1. Provide sensor viewing angles with L1T products; or
  2. Provide users a way to calculate sensor viewing angles for L1T products.
- ◆ **Providing the angles directly is problematic due to the resulting impact on product size**
  - The viewing geometry changes at SCA boundaries, so the representation would have to be at or near full resolution to capture the SCA transitions.
  - The viewing geometry is different for each band, so angles, or differences, would have to be provided for each band.
  - Brute force representation as “angle bands” would make angle layers larger than the L1T image product.
    - ❖ Even with compression, the “angle bands” would add ~30% to L1T product size
- ◆ **A alternate method was proposed that would generate additional “enhanced” metadata for inclusion in the L1T product, and provide a tool for users that would allow them to use this new data to compute viewing angles on demand.**
  - Proposal was documented in a white paper, which was subsequently accepted by the Science Team.

# “Enhanced” Metadata

## ◆ The new metadata file includes:

- L1T product image framing information (e.g., corner coordinates, pixel size, map projection parameters) that relates L1T pixels to Earth coordinates
- A rational function (ratio of polynomials) model that relates L1T line/sample to L1R line/sample and, therefore, time (one per band/SCA)

$$L1R_{Line} = L1R_{MeanLine} + \frac{(a_0 + a_1 * L1T_L + a_2 * L1T_S + a_3 * Hgt + a_4 * L1T_L * L1T_S)}{(1 + b_1 * L1T_L + b_2 * L1T_S + b_3 * Hgt + b_4 * L1T_L * L1T_S)}$$
$$L1R_{Samp} = L1R_{MeanSamp} + \frac{(c_0 + c_1 * L1T_L + c_2 * L1T_S + c_3 * Hgt + c_4 * L1T_L * L1T_S)}{(1 + d_1 * L1T_L + d_2 * L1T_S + d_3 * Hgt + d_4 * L1T_L * L1T_S)}$$

Where:

$$L1T_L = L1T_{Line} - L1T_{MeanLine}$$

$$L1T_S = L1T_{Sample} - L1T_{MeanSamp}$$

$$Hgt = Height - Height_{Mean}$$

a0 to a4, b1 to b4, c0 to c4, and d1 to d4 are model coefficients.

- ❖ This model, derived from the geometric grid, has achieved sub-pixel accuracy in the scenes tested so far
- An image timing model that relates L1R line numbers to time
- An ephemeris model that provides spacecraft ECEF positions vs. time
- A sun direction model that provides ECEF unit vectors for the sun vs. time
- A second set of rational function coefficients, fitted to the satellite viewing and solar illumination vectors themselves, is included for faster, but slightly less accurate, angle computation

# Angle Rational Functions (for the true enthusiast)

- ◆ The rational functions fitted to the viewing vector components are more complicated

- There is only one set per band, so they must accommodate SCA discontinuities by incorporating L1R coordinates

- ❖ 
$$\text{Sat}_X = \text{Sat}_{X\text{Mean}} + \frac{\text{Num}_X(\text{L1T}_L, \text{L1T}_S, \text{Hgt}, \text{L1R}_L, \text{L1R}_S)}{\text{Den}_X(\text{L1T}_L, \text{L1T}_S, \text{Hgt}, \text{L1R}_L, \text{L1R}_S)}$$

- ❖ 
$$\begin{aligned} \text{Num}_X(\text{L1T}_L, \text{L1T}_S, \text{Hgt}, \text{L1R}_L, \text{L1R}_S) \\ = a_0 + a_1 * \text{L1T}_L + a_2 * \text{L1T}_S + a_3 * \text{Hgt} + a_4 * \text{L1R}_L + a_5 * \text{L1T}_L^2 + a_6 * \text{L1T}_L * \text{L1T}_S \\ + a_7 * \text{L1T}_S^2 + a_8 * \text{L1R}_S * \text{L1R}_L^2 + a_9 * \text{L1R}_L^3 \end{aligned}$$

- ❖ 
$$\begin{aligned} \text{Den}_X(\text{L1T}_L, \text{L1T}_S, \text{Hgt}, \text{L1R}_L, \text{L1R}_S) \\ = 1 + b_1 * \text{L1T}_L + b_2 * \text{L1T}_S + b_3 * \text{Hgt} + b_4 * \text{L1R}_L + b_5 * \text{L1T}_L^2 + b_6 * \text{L1T}_L * \text{L1T}_S \\ + b_7 * \text{L1T}_S^2 + b_8 * \text{L1R}_S * \text{L1R}_L^2 + b_9 * \text{L1R}_L^3 \end{aligned}$$

- ❖ Where:

- ☐  $\text{L1T}_L = \text{L1T}_{\text{Line}} - \text{L1T}_{\text{MeanLine}}$

- ☐  $\text{L1T}_S = \text{L1T}_{\text{Sample}} - \text{L1T}_{\text{MeanSample}}$

- ☐  $\text{Hgt} = \text{Height} - \text{Height}_{\text{Mean}}$

- ☐  $\text{L1R}_L = \text{L1R}_{\text{Line}} - \text{L1R}_{\text{MeanLine}}$

- ☐  $\text{L1R}_S = \text{L1R}_{\text{Sample}} - \text{L1R}_{\text{MeanSample}}$

- ☐  $a_0$  to  $a_9$ , and  $b_1$  to  $b_9$ , are the RPC model coefficients.

- There are similar models for  $\text{Sat}_Y$ ,  $\text{Sat}_Z$ ,  $\text{Sun}_X$ ,  $\text{Sun}_Y$ , and  $\text{Sun}_Z$ .

- ◆ Note that it is still necessary to use the first-stage L1T-to-L1R RPCs to derive the L1R coordinates for this second-stage model

# Rigorous Angle Computation Method

- ◆ **For each pixel in the L1T image (band, L1T line/sample)**
  - Use the scene framing information to compute map projection (e.g., UTM) X/Y coordinates and convert to latitude/longitude
  - Use pixel height (if available from DEM) or mean height with latitude/longitude to compute ECEF ground point vector
  - Use ground point vector to calculate local vertical coordinate system
  - Use rational function model to compute corresponding L1R line/sample
    - ❖ Evaluate SCA-specific L1T-to-L1R RPCs for current band to find the one (or two) that return valid L1R sample numbers
    - ❖ Use that one (or two) to compute L1R line
  - Use L1R line to calculate image time
  - Use image time to interpolate ephemeris position
  - Use ground point vector and spacecraft position vector to compute ECEF line-of-sight (LOS) vector
  - Use ECEF LOS vector and local vertical coordinate system to calculate sensor viewing vector and corresponding angles
  - Use image time to interpolate sun direction vector
  - Use sun direction vector and local vertical coordinate system to calculate solar illumination vector and corresponding angles

# RPC Angle Computation Method

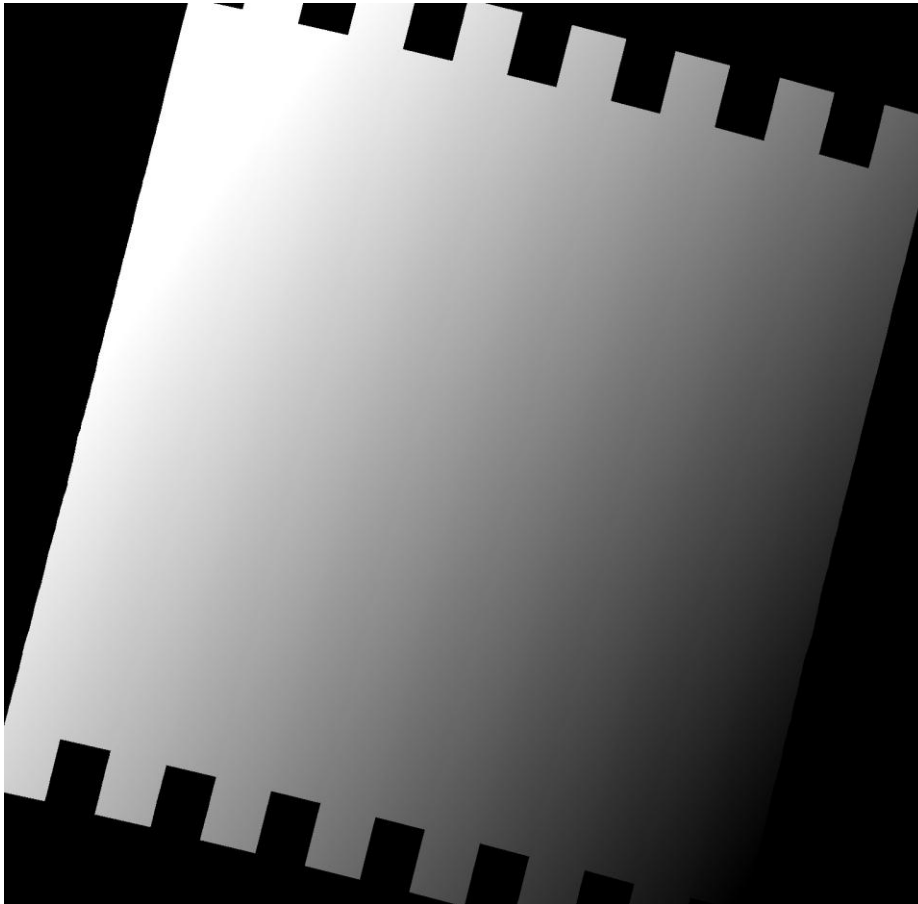
- ◆ **For each pixel in the L1T image (band, L1T line/sample)**
  - Use rational function model to compute corresponding L1R line/sample
    - ❖ Evaluate SCA-specific L1T-to-L1R RPCs for current band to find the one (or two) that return valid L1R sample numbers
    - ❖ Use that one (or two) to compute L1R line and sample
  - Use input L1T line/sample, L1R line/sample (from above), height (if available), and the RPCs for the current band to evaluate the satellite and sun viewing vector components
  - Compute satellite and solar zenith and azimuth angles from the vector components
  - Average the angles computed for each SCA that viewed the current ground point
- ◆ **Both angle computation methods write the resulting angles out to (optionally subsampled) image files**
  - One image file for satellite view angles and one for sun angles
  - Each file contains sequential zenith angle and azimuth angle “bands”
  - The angles are represented as 16-bit integers in units of degrees with a least count of 0.01 degrees



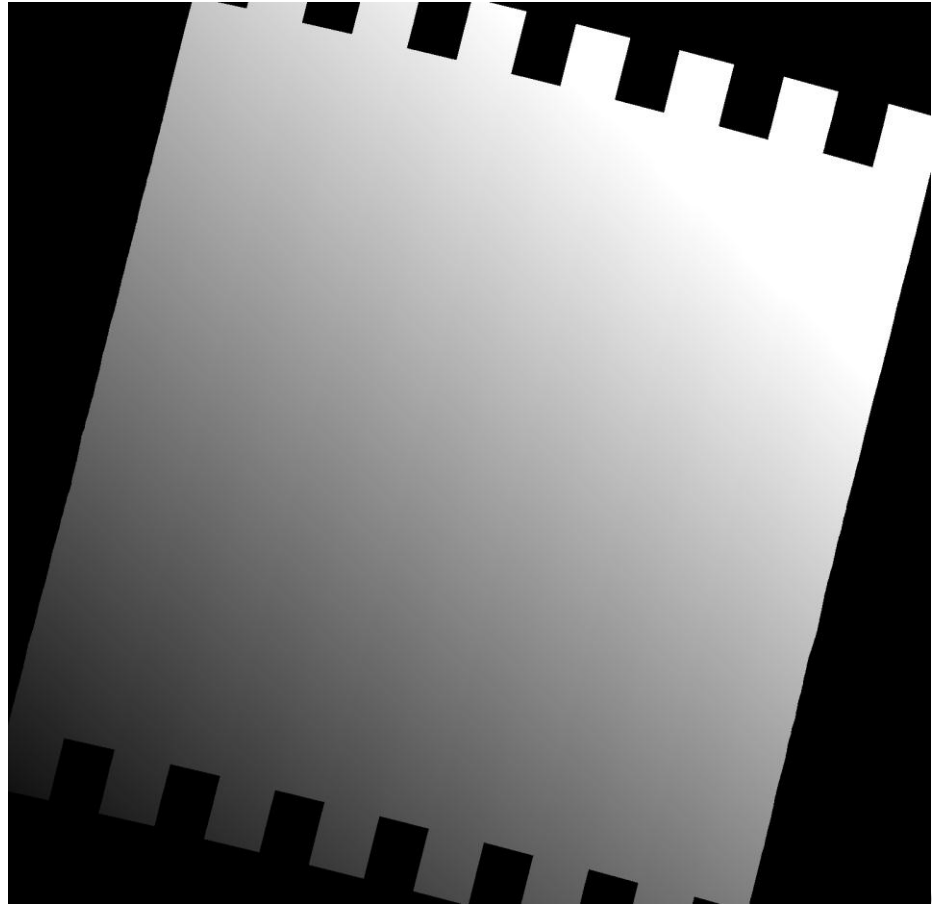
# Solar Angle “Band” Example – Band 7

- ◆ The sun angles vary smoothly across the image, with only small discontinuities at the SCA boundaries
  - The ragged SCA edges, shown here to demonstrate where the SCAs fall, are trimmed from the standard image product

Zenith Angle

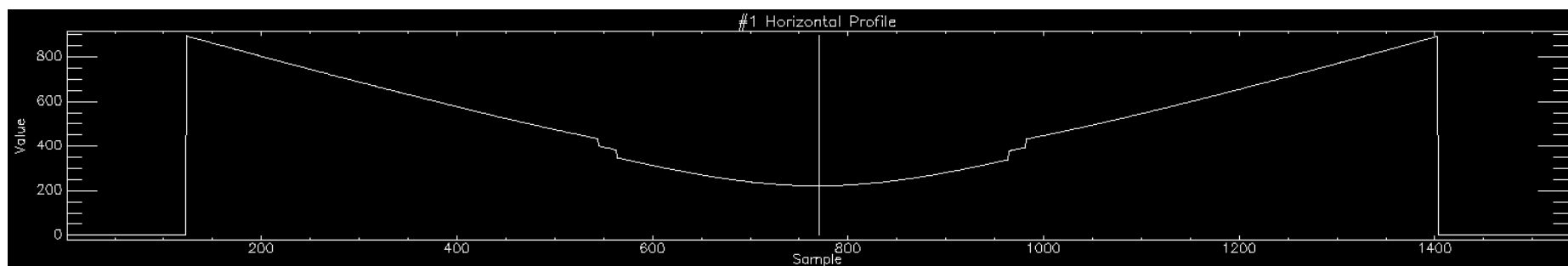


Azimuth Angle



# Satellite Zenith Angle “Band” Example – Band 10

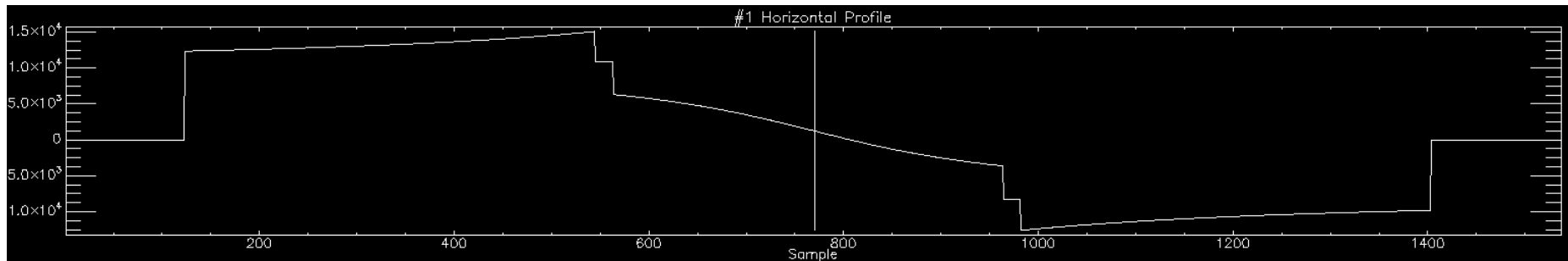
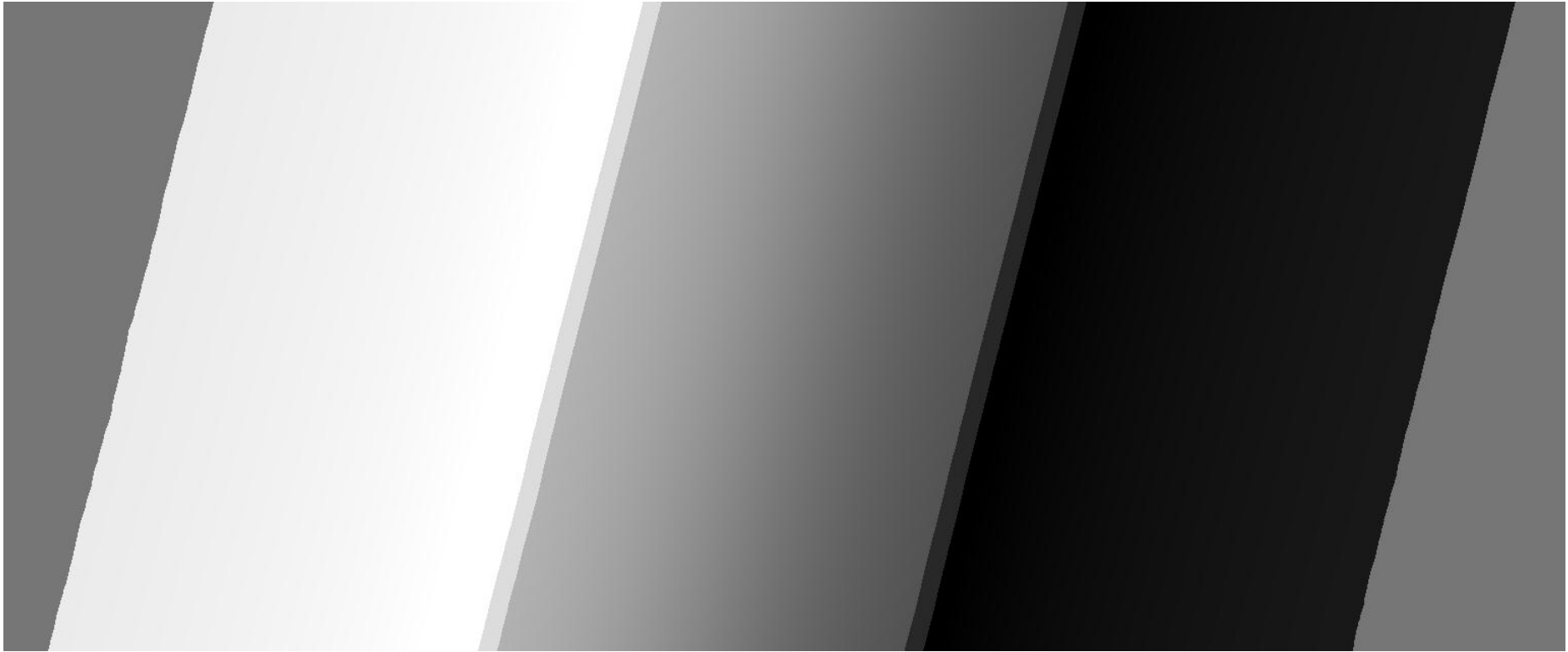
- ♦ The viewing geometry discontinuities at the SCA boundaries are clearly visible – note the averaging in the overlap areas





# Satellite Azimuth Angle “Band” Example – Band 10

- ◆ The viewing azimuth discontinuities at the SCA boundaries approach 90 degrees (see following charts)



# RPC Impact on Processing Speed

- ◆ **The software that uses the enhanced metadata to perform “rigorous” angle generation is fairly slow**
  - Some of the calculations and transformations required are relatively complex
  - This approach puts a fairly heavy computational burden on the user
    - ❖ The map projection, geodetic/geocentric conversion, and vector manipulation functions are relatively computationally intensive
    - ❖ Currently using IAS libraries to do these
  - Takes ~45 minutes to generate full resolution angles for a scene (all bands)
  - A subsampling option is available to obtain results faster
- ◆ **The RPC implementation is about 3 times as fast**
  - Takes less than 15 minutes per scene (full resolution)

# RPC and Terrain Impact on Accuracy – Sun Angles

## ♦ Sun angle accuracy vs. rigorous model with DEM

- Table shows maximum error in degrees
- Additional error due to RPC model is less than model accuracy (1 arcmin)
- Ignoring terrain has a larger effect though the additional error is still less than 2 arcmin in zenith angle and 4 arcmin in azimuth

MaxErr	Rig w/o DEM		RPC w/ DEM		RPC w/o DEM	
Band	Zenith	Azimuth	Zenith	Azimuth	Zenith	Azimuth
1	0.01	0.01	0.01	0.01	0.01	0.01
2	0.01	0.01	0.01	0.01	0.01	0.01
3	0.01	0.01	0.01	0.01	0.01	0.01
4	0.01	0.01	0.01	0.01	0.01	0.01
5	0.01	0.01	0.01	0.01	0.01	0.01
6	0.01	0.02	0.01	0.01	0.01	0.02
7	0.01	0.02	0.01	0.01	0.01	0.02
8	0.01	0.01	0.01	0.01	0.01	0.01
9	0.01	0.02	0.01	0.01	0.01	0.02
10	0.03	0.06	0.01	0.01	0.03	0.05
11	0.01	0.04	0.01	0.01	0.01	0.03

# RPC/Terrain Impact on Accuracy – Satellite Angles

## ♦ Satellite angle accuracy vs. rigorous model with DEM

- Tables show maximum error and standard deviation in degrees
- Additional error due to RPC model is less than 5 arcmin in zenith angle and 30 arcmin in azimuth
- Ignoring terrain has a much larger effect (the test area was in the Himalayas)

## ♦ The large DEM impact is due less to the inherent sensitivity of the angles to terrain height, than to the effect using terrain has on how the SCAs are mapped to the ground

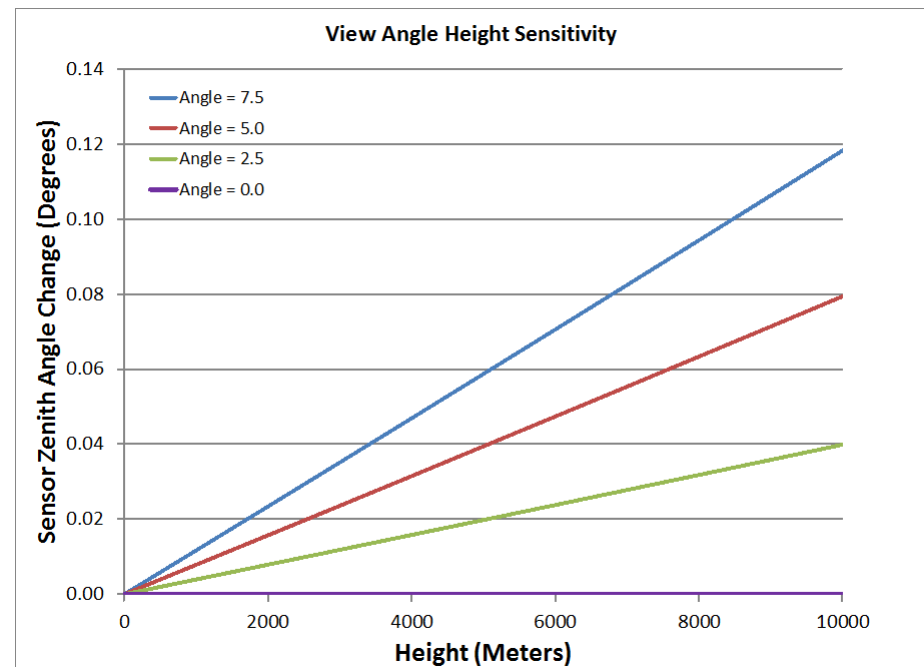
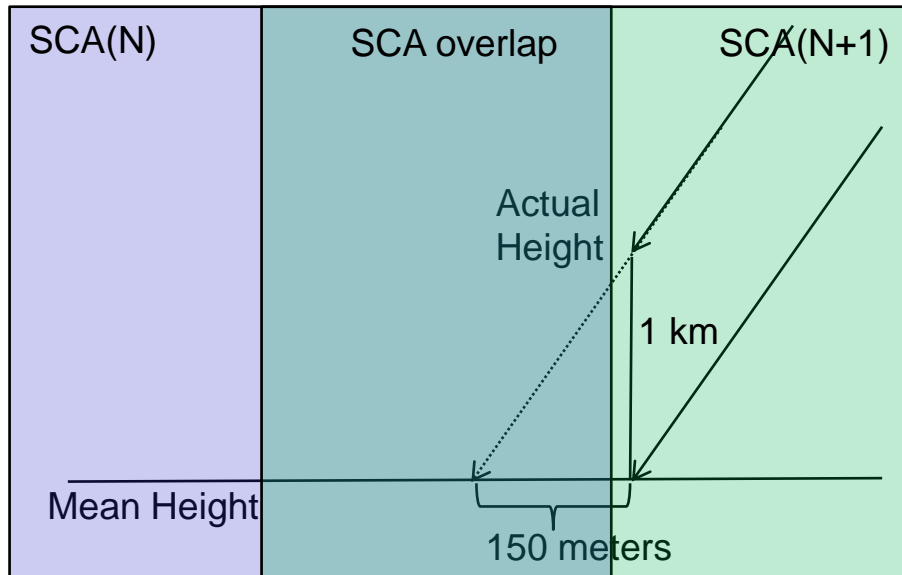
- Using a DEM changes where the SCA boundaries are calculated to fall, moving some pixels from one SCA to another
  - ❖ Switching from a forward-looking SCA to an aft-looking SCA can have a very large effect on azimuth

MaxErr	Rig w/o DEM		RPC w/ DEM		RPC w/o DEM	
Band	Zenith	Azimuth	Zenith	Azimuth	Zenith	Azimuth
1	0.28	82.66	0.05	0.10	0.27	82.70
2	0.28	62.72	0.07	0.46	0.23	63.15
3	0.28	87.35	0.03	0.07	0.27	87.34
4	0.28	84.21	0.03	0.07	0.27	84.19
5	0.28	84.83	0.04	0.08	0.28	84.83
6	0.28	88.08	0.03	0.06	0.28	88.07
7	0.29	87.45	0.03	0.06	0.27	87.44
8	0.22	28.78	0.07	0.17	0.21	28.78
9	0.28	87.48	0.03	0.06	0.28	87.47
10	0.73	86.92	0.06	0.04	0.73	86.94
11	0.54	55.81	0.03	0.03	0.55	55.81

StdDev	Rig w/o DEM		RPC w/ DEM		RPC w/o DEM	
Band	Zenith	Azimuth	Zenith	Azimuth	Zenith	Azimuth
1	0.012	0.695	0.005	0.008	0.012	0.695
2	0.012	0.546	0.005	0.015	0.012	0.546
3	0.012	1.049	0.006	0.008	0.013	1.049
4	0.012	0.935	0.006	0.008	0.013	0.935
5	0.012	0.823	0.005	0.008	0.013	0.823
6	0.013	1.316	0.006	0.009	0.014	1.316
7	0.013	1.214	0.006	0.009	0.013	1.214
8	0.012	0.400	0.004	0.009	0.012	0.400
9	0.013	1.421	0.007	0.009	0.014	1.421
10	0.016	1.561	0.012	0.007	0.020	1.561
11	0.015	1.114	0.006	0.008	0.016	1.114

# Height Impact on View Angle Error

- ◆ The viewing zenith angle sensitivity to ground target height is plotted below for sensor angles ranging from zero (nadir) to 7.5 degrees (edge of FOV)
  - At the edge of the FOV, a terrain variation from the scene average of 1 km will lead to a zenith angle error of about 0.012 degrees (0.7 arc minutes)
- ◆ The effect on horizontal position and, hence, which SCA sees a given ground target is more sensitive
  - A 1 km terrain variation from the scene average leads to a horizontal displacement of ~150 meters
  - Large impact on viewing azimuth



# Current Status



- ◆ **A standalone (no references to external IAS libraries) version of the angle generation software has been created**
  - GNU C/Linux based
  - Has been provided to Dr. Stu Biggar at the University of Arizona for testing
  - Also provided Stu with 6 sample products
- ◆ **An algorithm description document that describes the algorithm and prototype software has been written**
- ◆ **Additional sample products (enhanced metadata) will be generated and provided, along with the prototype software, to additional test users**
  - Need volunteers from the Science Team
  - Need nominations for sample product scenes
- ◆ **A CCR will be needed to implement enhanced metadata generation in the production system**
  - Need confirmation from test users that this is the correct solution



# Open Questions and Possible Enhancements

- ◆ **Should we continue to average the image data in SCA overlap areas or is a step transition preferable?**
  - Makes viewing geometry less ambiguous but creates larger discontinuities
  - Would require a relatively minor change to the resampler to implement
- ◆ **Should DEM or explicit SCA location data also be included with the L1T products to make angle computation more accurate?**
  - Biggest impact is due to the effect height has on determining the source SCA for each pixel, but this only impacts pixels near SCA boundaries
  - The SCA coverage information could be provided directly by including an “SCA map” with the products
    - ❖ Similar in concept to the L7 “gap mask”
    - ❖ Would require new logic in the resampler to implement
- ◆ **Is it important for a given pixel to have all spectral bands come from the same SCA (i.e., have the same viewing geometry, as much as possible)?**
  - Would require (relatively complex) new logic in the resampler
  - This obviously doesn't apply to reflective vs. thermal bands

# Summary and Recommendations

- ◆ **A method that allows users to calculate per pixel sensor view angles and solar illumination angles for L1T products has been developed and prototyped**
  - Generates an additional “enhanced” metadata file that would be added to L1T products when created
  - Includes a user tool that operates on the new file to generate the angles
    - ❖ Standalone version of the tool has been distributed to one test user
    - ❖ Need additional test user volunteers
  - User tool can work with or without terrain data input
    - ❖ Ignoring terrain can degrade accuracy of computed angles
    - ❖ Biggest impact is on viewing angles (azimuth) due to less precise location of SCA transitions
- ◆ **Recommendations**
  - Allow additional test users from the Science Team to work with the user tool and selected test products
    - ❖ Need volunteers
  - If current approach seems workable, move forward with enhanced metadata CCR
  - Continue to investigate/prototype implementing an SCA map to identify the source of each L1T pixel